

Analog engineers get analysis tools

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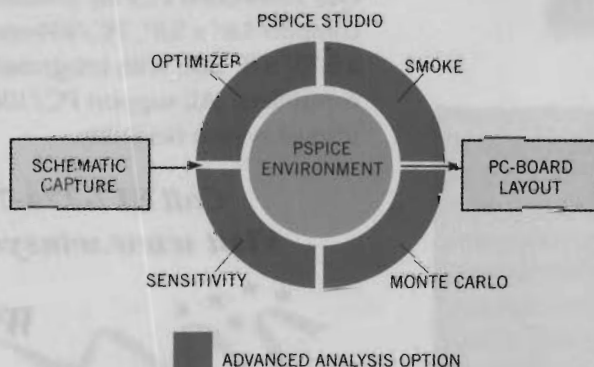
mean, and median values; and standard deviation.

Stress, or "smoke," analysis improves the reliability of a design by reducing the likelihood of hardware failure. Designers can analyze a circuit looking for devices that exceed various safe operating limits, such as overvoltage, power dissipation, secondary breakdown, and junction temperature before the prototype "goes up in smoke."

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Integrated Circuit Susceptibility to Conducted RF Interference

FRANCO FIORI

The complexity of today's ICs provides many avenues for conducted interference as well as associated challenges for the product designer.

In the presence of electromagnetic pollution, cables of electronic systems can act as receiving antennas and capture disturbances (see Figure 1). Owing to the superimposition of interference on intentional signals, electronic equipment modules could display unwanted behavior.

Sources of electromagnetic interference (EMI) include lightning events, radio transmitters, radar devices, and transmitters of wireless communication systems. Unwanted interference can also be produced by the operation of electronic circuits.

The immunity of electronic equipment to EMI typically can be increased by using a metal can as a shielding box, by incorporating filters on printed circuit boards (PCBs), and by employing filtered connectors. However, these measures often are expensive and incompatible with volume applications. In such cases, it becomes necessary to design robust integrated circuits (ICs).

Today's manufacturing technology makes it possible to design complex ICs in which analog and digital circuits are integrated on the same die. Unfortunately, analog circuits are usually susceptible to continuous conducted radio-frequency interference (RFI), while digital circuits exhibit high susceptibility to pulsed conducted interference. Thus, interference collected into complex ICs induces intermodulation, cross-modulation, rectification, and other deleterious effects that cause upsets in the operation of the circuits.

This article examines the nature of the RFI-induced problems to which ICs are susceptible, focusing on the effects of RFI on nonlinear active devices, operational amplifiers, and digital ICs.

Integrated circuits can collect interference, causing intermodulation, cross-modulation, rectification, and other electronic disturbances.

RFI Effects in Integrated Active Devices

All electronic devices are inherently nonlinear. Every nonlinearity, when driven by a large signal, produces distortion of the output signal. For instance, in the circuit shown in Figure 2, continuous-wave RFI is applied to a forward-polarized diode. The current through the diode is not sinusoidal, and the mean value is different from that obtained without interference. The experimental results achieved with such a test setup are reported in Figure 3 and show



technologies in our past proceedings, they are always available.

Our second level is the development and the ongoing refinement of device-testing standards. Probably one of the greatest achievements of our standards organization is in the development of device-testing standards so that engineering interests can not only confirm their designs but support their development. If you don't have a reference for what you have developed through device and product design, if you can't test it and quantify its performance, how are you going to know? Now that you make a device, how do you control the process that protects the device? And that comes from 20.20 because it covers the environment, the materials, and the people in all aspects, from training on through the process. If I say in my plan that I'm going to use a new guideline to control my process in which ESD protection is critical, who is to say I've done it properly? If I have a good reference, a guideline like 20.20, I can have my facility certified and confirmed by an independent, ISO-level third party.

There is a vertical structure depending on the interests and the commitment of an organization, but that's only one side of the coin. Where do you get the people? How do you develop the people? This is the third level of our response. We develop people through providing multitiered education through our national tutorial, which includes basic and advanced design. We're trying to provide input to all levels of the organization that have to make decisions and design processes and products. We're trying to cross the multiplicity of lines in terms of subject matter. The RF industry often has different interests than the MR industry, for instance.

We provide education through our local chapters and regional tutorial programs. We prepare individuals to take professional-level certification exams from an independent third party, in this case NARTE. Not only can you certify a facility, you can certify an individual's knowledge level in dealing with either the technical or engineering issues in relationship to the process and product. The association's point of

view is that we want to provide engineers, engineering teams, and corporations with a multiplicity of input. We're not going to design products for them, any more than we do market analysis for people who make static-control materials. But to provide guidelines, information, and education, to promote some harmony in the industry, to help the industry develop ESD-

control technology—that's the challenge, and that's where the fun is, when you get right down to it, because this is the heart of the association.

Stephen Halperin can be reached at shalperin@halperinassoc.com. For more information about the ESD Association and the EOS/ESD Symposium, visit <http://www.esda.org>. ■

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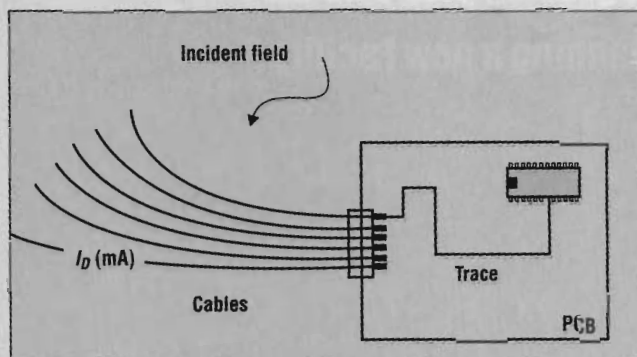


Figure 1. Incident field coupled with cables and PCB traces, detectable as dc current measured in milliamperes.

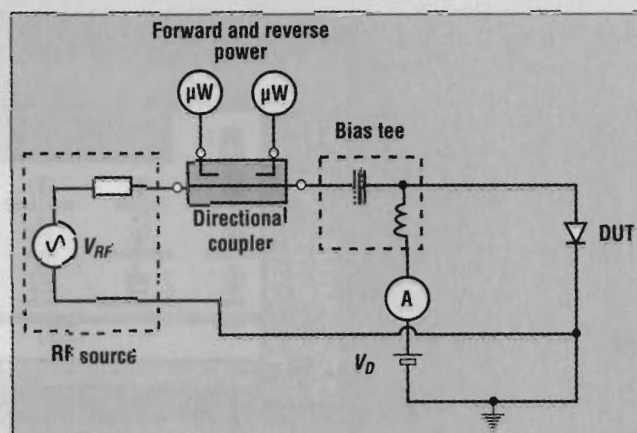


Figure 2. Schematic description of the test setup required to evaluate the upset due to RFI of the dc quiescent operating point in a diode.

the modification of the diode dc current (I_D) versus the dc voltage (V_D) applied to its terminals.

The rectification phenomenon modifies the dc quiescent current level, introducing an offset whose amplitude is dependent on the radio-frequency (RF) signal amplitude and frequency.

Susceptibility of Bipolar Transistors. An RF voltage applied to the base-emitter junction of a bipolar transistor, polarized in the active region, induces a variation of the transistor quiescent operating point because the emitter

All electronic devices are inherently nonlinear. Every nonlinearity, when driven by a large signal, produces distortion.

current crowding and base-emitter junction rectification phenomena occur.¹⁻³

The quiescent-operating-point upset due to RFI applied to the base-emitter junction can be experimentally evaluated by the test bench diagrammed in Figure 4. In this setup, the RF power delivered from the RF source and that

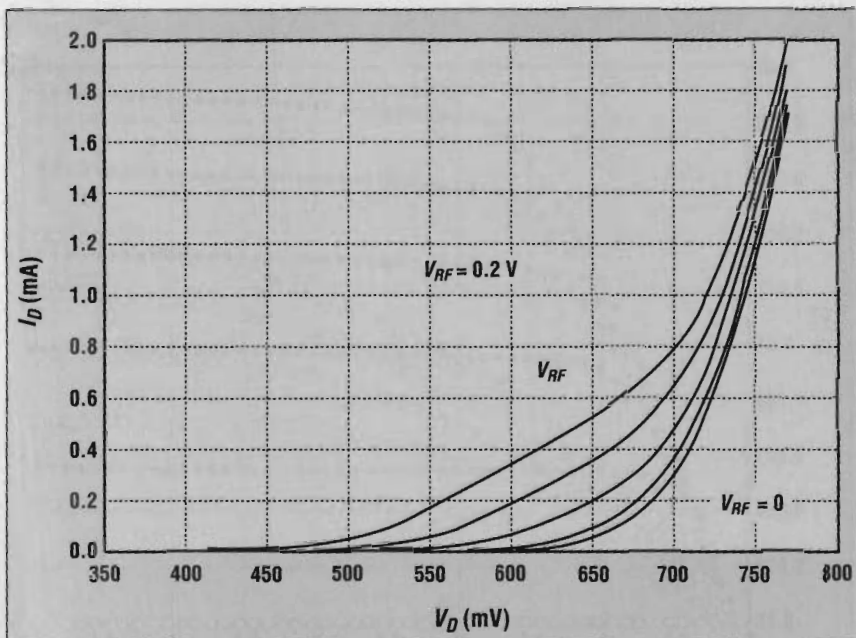


Figure 3. Effects of RFI on the characteristics of a forward-polarized diode. V_D and I_D are, respectively, the mean value of the diode voltage and current. This graph depicts several I-V diode characteristics obtained with RFI of a different amplitude.

reflected by the device under test (DUT) can be measured by two power meters connected to a directional coupler. The bias tee circuit connected to the transistor base terminal allows the superposition of interference on the base-emitter voltage. Another bias tee connected to the collector makes possible the supply of the DUT and confines the RF signal to the load Z_L .

Running the test depicted in Figure 4 can generate transistor output characteristics like those shown in Figure 5. The experimental results indicated by circles are measurements of dc voltages and currents made when an interfering signal was applied to the base-emitter junction. Crosses in the same figure indicate results obtained without interference. Additional experimental results (not shown

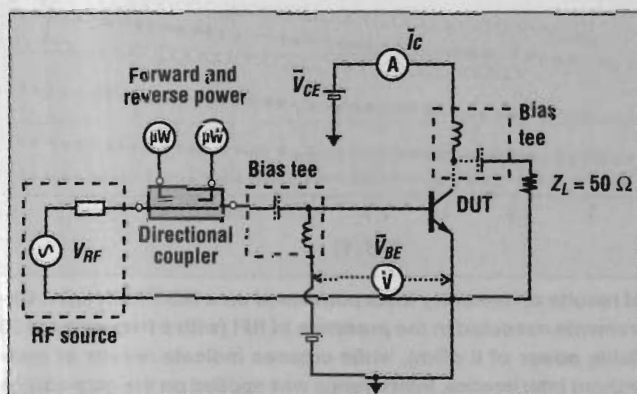


Figure 4. Schematic description of the test setup for the evaluation of the upset induced by RFI in the dc quiescent operating point of a bipolar transistor. I_C , V_{CE} and V_{BE} , respectively, are the mean values of the collector current, the collector-emitter voltage, and the base-emitter voltage.



Integrated circuits can be designed to minimize conducted interference.

here) displayed a set of output characteristics pertinent to the case of RF disturbance applied between the collector and the emitter terminals.

Predicting Behavior Responsive to RFI. Nowadays, simulation tools such as SPICE (Simulation Program with Integrated Circuit Emphasis) aid in the design of analog ICs. A circuit simulator uses a nonlinear circuit model of each

RF interference induces in a bipolar transistor emitter current crowding and rectification phenomena.

active component, and predicts voltages among nodes and currents through circuit branches.

For instance, the model of Gummel and Poon considers the bipolar transistor as a one-dimensional device, and a large-signal equivalent circuit describes relations by which voltages and currents at the four terminals can be evaluated.⁴ However, RF interference induces in a bipolar transistor emitter current crowding and rectification phenomena, both of which require a distributed modeling. Prediction of dc quiescent-operating-point shift due to RFI applied to the base-emitter junction can be undertaken with the help of the modified Gummel-Poon model, which also operates in SPICE-like simulators.⁵

Susceptibility of MOS Transistors. In a way similar to that used to evaluate the susceptibility of bipolar transistors, a test setup can be used to evaluate the effect of RFI in metal oxide semiconductor field-effect transistors (MOSFETs). The mean value of the drain current versus drain-to-source voltage is reported in Figure 6. In that figure, the circles

represent cases of voltages and currents measured when RF disturbance was added to the dc gate-source voltage and the crosses represent results obtained without RFI. Disturbances on the gate-source terminals increase the dc drain current.

MOS transistors can be considered less susceptible than bipolar transistors, since RFI induces in a bipolar transistor a variation of collector current higher than that induced in the drain current of an MOS transistor. As a matter of fact, field-effect transistors are inherently less susceptible to RFI than bipolar transistors because of their smoother nonlinearity.

Susceptibility of Operational Amplifiers

Operational amplifiers (op amps) are circuit blocks widely used in the design of analog and mixed-signal circuits. Though popular, op amps are extremely susceptible to conducted RFI. For this reason they have been the subject of many technical papers.^{1,6}

A circuit composed of an op amp with a negative-feedback network could show an unwanted output offset if RFI reaches the op amp's inverting or noninverting input. For example, if RFI is applied to the noninverting input in a voltage follower configured as in Figure 7, a dc output offset voltage can be observed. Experiments performed on general-purpose op amps such as the uA741 have shown that the dc output offset voltage amplitude is dependent on the interference frequency, as shown in Figure 8. In addition, the offset value depends on the properties of the feedback network and on the amplitude of the disturbance.

The generation of offset observed at the output can be explained with reference to the nonlinearity of the op amp. If interference drives the op amp under test in slew-rate limitation and the positive slew rate is different from the negative one, then output offset voltage is generated. Figure 9 shows the output voltage of an op amp in voltage follower configuration, with an asymmetric slew rate and driven in slew-rate limitation by RFI. Interference also drives the nonlinearity of transistors of the differential stage, and an extra output offset voltage appears.

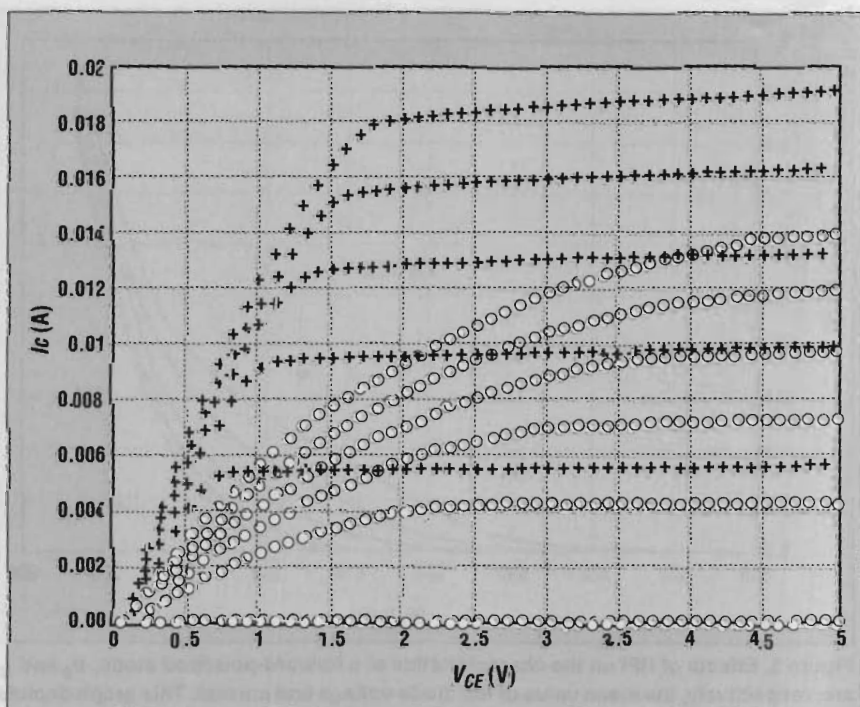


Figure 5. Experimental results of immunity tests performed on a bipolar transistor. Circles represent measurements executed in the presence of RFI (with a frequency of 1 MHz and source available power of -10 dBm), while crosses indicate results of measurements executed without interference. Interference was applied on the base-emitter junction.

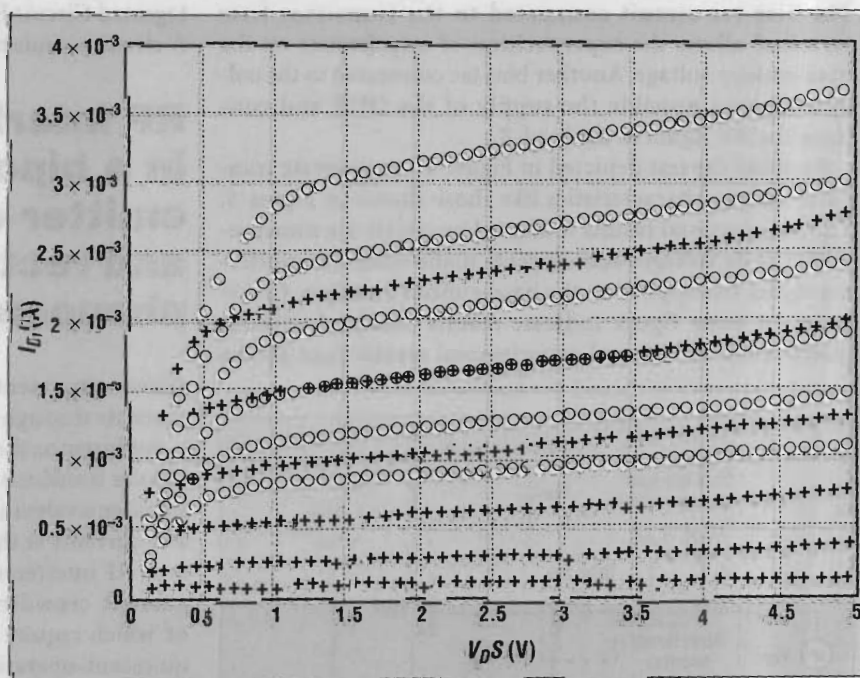


Figure 6. Experimental results of immunity tests performed on a MOS transistor. Circles represent measurements executed in the presence of RFI (with a frequency of 50 MHz and source available power of 0 dBm), while crosses indicate results of measurements executed without interference. Interference was applied on the gate-source terminals.

Susceptibility of Digital Circuits

The discussion now turns to the effects of conducted interference on the behavior of digital ICs. In fact, most in-

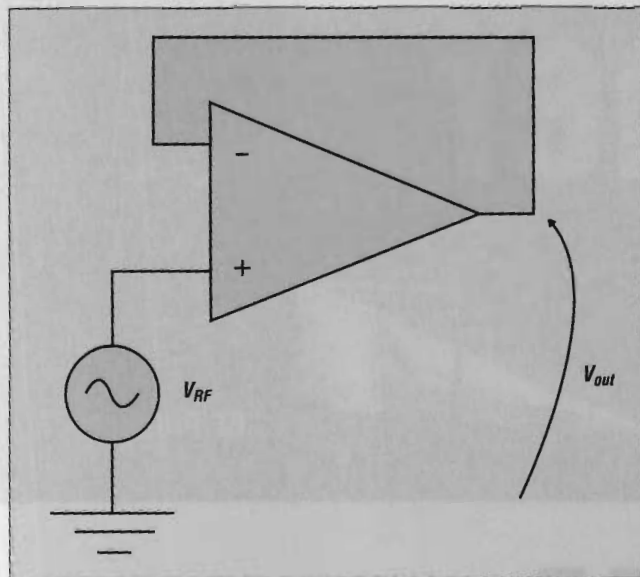


Figure 7. Noninverting voltage follower.

interference is collected by cables and PCB traces while interference collected by package lead-frame and bonding interconnections is negligible. Digital signals corrupted by interference, which are applied to the input of a line receiver, can be described by the scheme appearing in Figure 10.

Common digital circuits are very susceptible to pulsed interference, such as burst and electrostatic discharge (ESD), while they offer good immunity to RF interference. Because of their amplitude and fast edges, burst and ESD can very easily induce logic errors, especially if their effect is latched in a memory device. Particular care must be paid to the set of reset pins, which can be triggered by a pulse disturbance.

Static Errors. In the case where a static signal has been applied to the input of a digital receiver, interference of amplitude higher than the commutation threshold induces the commutation of the receiver output signal.

Regarding RFI, a distinction must be made between disturbances within the bandwidth of the receiver under test and RF signals at frequencies higher than the device maximum operating frequency. The signal has a frequency compliant with the bandwidth of the DUT: then, if the RF voltage is higher peak to peak than the logical dynamic, the output will switch according to the input disturbance. If the signal is over the maximum operating frequency of the DUT, then the possibility of causing an upset of a logic level so as to change the logic output state is confined to very strong disturbance amplitudes, well over the usual test levels. However, the RFI induces a modification of the logic levels for

both bipolar and complementary metal oxide semiconductor (CMOS) logic circuits, along with a consequent reduction of noise margins.⁷

Dynamic Errors. Interference collected by a digital communication system may induce dynamic failures. The presence of interference over a digital signal can modify the time at which line-receiver commutation occurs, and timing failures can be induced.

Common digital circuits offer immunity to RF interference but are susceptible to pulsed interference such as burst and ESD.

Usually, CMOS-receiver dynamic failures occur before static ones do, and these dynamic failures could be the cause of failures in very-large-scale integration (VLSI) devices. Because of the extra propagation delay of the line receiver due to interference, the logic gate's settling time and hold time, and the sampling-time masks, cannot be respected. The extra propagation delay induced by RFI in a line receiver depends on the amplitude and the frequency of the disturbing RF signal and also on the phase of the logic input signal. Figure 11 portrays the modification of the line-receiver propagation delay induced by 20-MHz RFI with an amplitude of 1 V.^{8,9}

Conclusion

In summary, analog cells immune to conducted RFI can be obtained by designing low-distortion circuits. Using MOS transistors instead of bipolar transistors can achieve this end. Choosing circuit topologies that account for pre-distortion and postdistortion can also help obtain desired

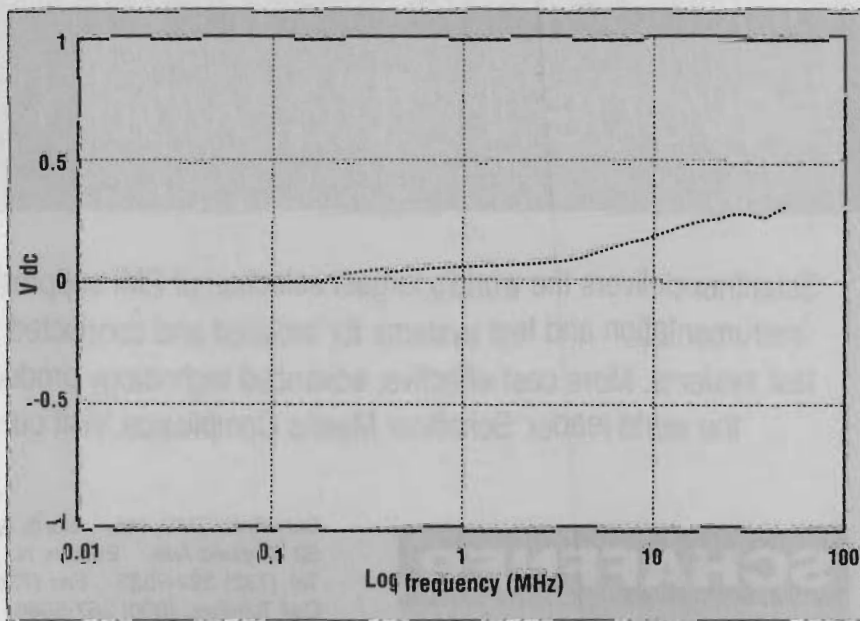


Figure 8. Output offset voltage of a uA741 op amp in voltage follower configuration.

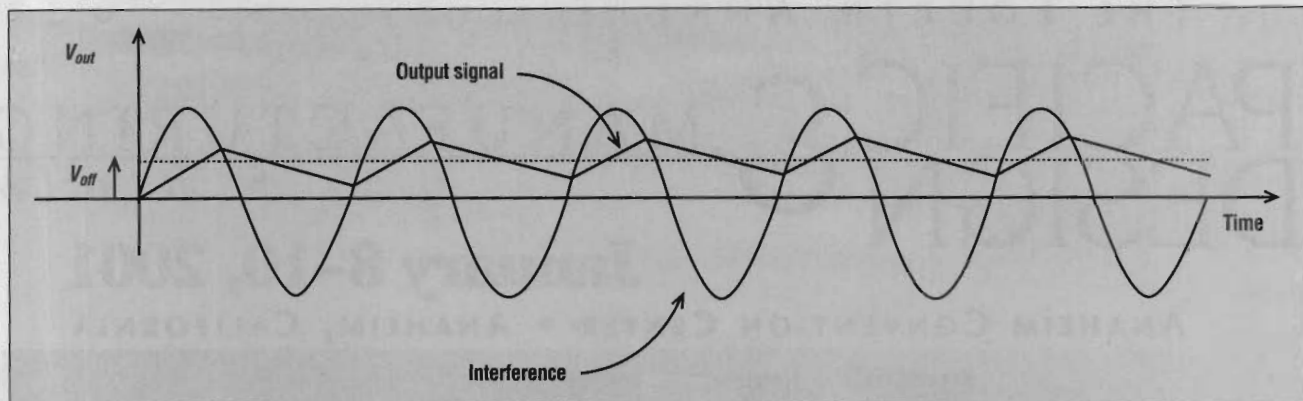


Figure 9. Output offset voltage due to the difference between positive and negative slew-rate limitation.

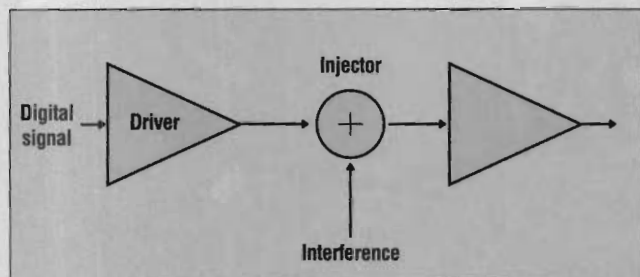


Figure 10. Representation of a digital signal corrupted by interference and applied to the input of a line receiver.

immunity. With regard to op amps, controlling slew-rate symmetry can greatly reduce output offset voltage. Finally, common digital circuits are very susceptible to pulsed interference such as burst and ESD, whereas they offer good immunity to conducted RF interference.

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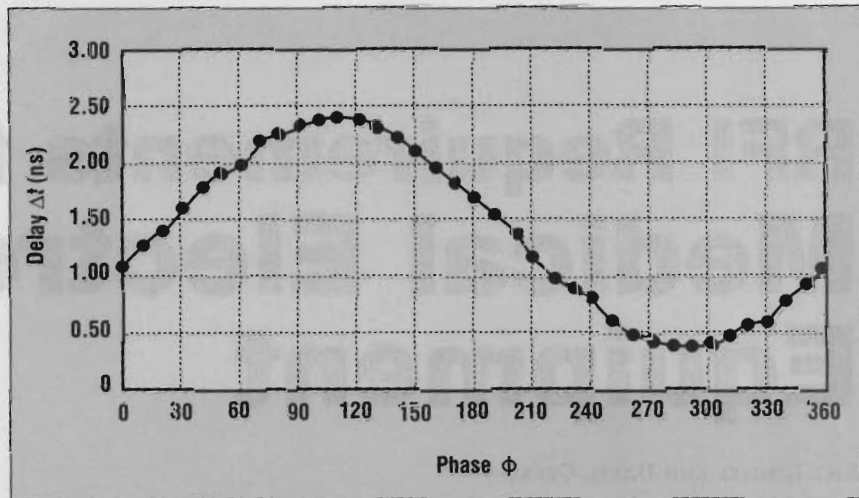


Figure 11. Extra propagation delay induced in a line receiver by RF interference over a digital signal. The RFI has a frequency of 20 MHz and amplitude of 1 V.

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RFI Requirements for Medical Electronic Equipment

BILL KIMMEL AND DARYL GERKE

Medical electronics can be found in greatly varying electromagnetic environments. The problem is that one set of RFI requirements does not meet the needs of all types of equipment. An engineering perspective may help guide the latest regulatory efforts.

Electronics engineers tend to talk about electromagnetic interference (EMI) in medical electronics in a collective sense. But, in actuality, medical electronic equipment covers such a wide span of equipment types and environments that it is not realistic to apply a single set of requirements across the board. Some highly sensitive equipment cannot bear even a moderate EMI environment, yet other devices must be designed to withstand all the interference modern technology can produce.

In recognition of this disparity, the second draft revision of IEC 60601-1-2 has a much expanded scope, defining a number of equipment categories and environments, and clarifying requirements for each.¹ And there is more to come. Many points are yet to be expanded. Although the revision better defines the requirements, the longer document requires much closer study to determine what parts apply to a given equipment type. The draft revision is not expected to be in effect for at least another year; however, its contents and their implications are relevant now.

The Association for the Advancement of Medical Instrumentation (AAMI) has proposed this document as a national standard. The Food and Drug Administration (FDA) made a significant contribution to this draft, seeking to improve areas containing deficiencies, notably the standard's explanation for determining pass/fail criteria for each equipment type. Although FDA has recognized the current version of IEC 60601-1-2, existing guidance documents still take



Illustration by BRAD HAMANN